NASA SP-5028

TECHNOLOGY UTILIZATION REPORT

Technology Utilization Division

TECHNICAL AND ECONOMIC STATUS OF MAGNESIUM-LITHIUM ALLOYS

A Report to

Industrial and Defense Management

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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A Report to
Industrial and Defense Management

by Paul D. Frost

Prepared under contract for NASA
by Battelle Memorial Institute

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D. C. August, 1965

NOTICE

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Foreword

The Administrator of the National Aeronautics and Space Administration has established a Technology Utilization Program for the rapid dissemination of information on technological developments that appear to be useful for industrial application. From a variety of sources, such as NASA research centers and NASA contractors, space-related technology is screened, and that which has potential industrial use is made generally available.

This publication is one of a series designed to provide such technological information.

This study of the magnesium-lithium alloys is a report to management on the general characteristics of the alloys, their current applications, and economic considerations for their future use. One objective of this report was to investigate the progress being made in the application of the new ultralight magnesium-lithium alloys in the space industry and to disseminate this information to those organizations not acquainted with the alloys and their applications. The second objective of the work was to explore the possible future usefulness of the alloys in applications not oriented to space flight and to define the technical and economic requirements for establishing such commercial use.

The report does not include detailed engineering information.

Director
Technology Utilization Division
Office of Technology Utilization

Contents

Introduction

Magnesium-lithium alloys are the lightest structural metals commercially available. The alloy LA141A (Mg–14%Li–1%Al) is 22 percent lighter than pure magnesium and 27 percent lighter than pure beryllium. It has as low a density as most plastics but has the stiffness (modulus of elasticity) of a metal. This combination of lightness and stiffness has established magnesium-lithium alloys as the newest aerospace material. Industry interest in the alloys for missile and space-flight purposes has come about only during the last 3 years, despite the fact that serious development of the alloys was started in this country as early as 1944. Like many other technical developments, the magnesium-lithium alloys were developed for a purpose that did not materialize, and they existed for a number of years before they were "discovered" by the aerospace industry.

The National Aeronautics and Space Administration was largely responsible for the introduction of these light materials to the manufacturers of missile and space hardware through its sponsorship of the first research on the evaluation of the alloys for missile and space use (ref. 31). The report on that research recommended the Mg–14%Li–1%Al (LA141A) alloy as the composition having the greatest immediate potential. The report, which received wide distribution, presented mechanical properties, corrosion resistance, weldability, and physical properties of the alloy. Since 1960, aerospace companies, notably the Lockheed Missiles and Space Company and the Federal Systems Division of International Business Machines Corporation, have made good use of the information presented in the NASA report and have generated much more data on the properties and use of the LA141A alloy.

The question naturally arises, "Will the results of the efforts made on these alloys for aerospace usage be adaptable to commercial and industrial applications?" The answer to this question obviously involves economic, as well as technical, consideration because material and manufacturing costs are always major factors in the commercial use of any new alloy. In the aerospace industry emphasis must be on saving weight. Every pound saved in a payload represents, literally, thousands of dollars saved in booster design and materials. For this reason, extremely expensive metals, such as beryllium, may actually be more economical to use than a heavier, less costly alloy.

The magnesium-lithium alloys are considerably less expensive than beryllium, with respect to both material and fabrication costs. However, they are considerably more expensive than commercial magnesium alloys. Therefore, while it is being demonstrated that the magnesium-lithium alloys are technically and economically sound materials for space applications, it is not clear what their future usefulness might be for commercial products in which cost is a major factor. This report is concerned with both the present space usage and the future commercial usefulness of the alloys.

Summary of the Characteristics of Magnesium-Lithium Alloys

The magnesium-lithium alloys are characterized by lightness and good formability. They are light by virtue of their lithium content. Lithium, which has a density about half that of water, is the lightest of all elements except those that normally exist as gases. The alloys are formable because of their microstructure. Lithium tends to convert the difficult-to-form hexagonal crystal structure of magnesium to the inherently ductile and formable cubic structure. It requires about 5.7 percent of lithium for partial conversion of the structure and about 10.3 percent to produce a completely cubic crystal structure. The LA141A alloy having 14 percent lithium is completely cubic. With this much lithium the density is only 1.35 g/cm^3 (0.049 lb/in^3) as compared with 1.74 g/cm^3 (0.063 lb/in^3) for pure magnesium.

The magnesium-lithium system is very amenable to alloying with many other metals, most effectively with aluminum, zinc, cadmium, and silver. Gold, thallium, and mercury are also readily alloyed. (In a moment of discouragement during the early days of their development, a research engineer once remarked that the magnesium-lithium system seems to alloy most easily with all the metals that are either heavy or expensive, or both).

When relatively small amounts of alloying elements are used in the magnesium-lithium base, the strength is improved over that of the binary alloys and can be maintained at these modest levels for an indefinite time at 150° to 200° F. The data in table 1, taken from early Battelle research, show examples of these alloying effects.

Alloys of the above type, although not having high strength, are stable during use at the temperatures mentioned above. They are also very ductile, and they have lower densities than more highly alloyed compositions.

Alloys that contain a total of about 10 to 20 percent of one or more of the elements aluminum, zinc, cadmium, or silver respond more vigorously to heat treatment than the dilute alloys and can attain very high strengths, e.g., tensile strengths between 50 000 and 65 000 lb/in^2. Examples of such alloys are Mg-12%Li-15%Cd-5%Ag, Mg-14%Li-10%Al and Mg-12%Li-20%Zn. Unfortunately, the strength diminishes gradually at 150° F or higher because of the diffusion and precipitation of the alloying elements. Thus, the alloys lose strength at 150° to 200° F as aluminum alloys do at 250° to 400° F. This instability, or tendency to lose strength at low temperatures, has been studied by many investigators but has not yet been overcome.

In the research conducted at Battelle for NASA it was decided, after all types of alloys had been considered, that the low-strength, stable type of alloy would be most appropriate for application to hardware in the aerospace industry. One of the alloys selected, Mg-14% Li-1-1.5%Al (LA141A) had the required stability, low density, good formability, and reasonable strength. The LA141A alloy has now become a commercial material, and it is this alloy that is shown in the applications described in the next section. Mechanical and physical properties of LA141A and some properties of other magnesium-lithium alloys that have not been made available commercially are presented in a later section.

TABLE 1.—*Effects of Alloying Elements Used in the Magnesium-Lithium Base*

Nominal alloy composition, % (balance Mg)	Yield strength, lb/in.²	Ultimate strength, lb/in.²
11Li	11 700	17 300
11Li–0.5Al	18 100	21 400
11Li–2.0Al	19 900	27 300
11Li–4.0Zn	19 100	26 500
11Li–4.0Ag	18 200	23 200
11Li–4.0Si	17 900	24 000

Current Industrial and Government Applications

Almost all of the applications of the magnesium-lithium alloys at the present time are in the aerospace field. The only exceptions are the M113 armored vehicle development program sponsored by the Army Tank-Automotive Center at the Dow Metal Products Company and the Food Machinery Corporation, which has recently been completed, and a current ordnance application study at Hughes Aircraft Company. In the following sections the activities of the companies and Government agencies which manufacture or develop hardware are described.

LOCKHEED MISSILES AND SPACE COMPANY (LMSC)

The Lockheed Missiles and Space Company at Sunnyvale, California, has made what is probably the greatest use of LA141A alloy in aerospace equipment. Starting in early 1962, this company purchased and evaluated a major part of the mill products made by Brooks and Perkins, Incorporated. The alloy has been used to compile extensive engineering test data and to fabricate components for various models of the Agena booster and a number of satellites that the Agena has put into orbit.

Lockheed has been using the magnesium-lithium alloy as a substitute for other magnesium alloys, aluminum alloys, and beryllium in parts that carry low loads and do not reach temperatures much above 100° F. The principal criterion applied by the Lockheed engineers in selecting LA141A alloy for a given part is the ratio of elastic modulus to density. The strength-to-weight ratio of the alloy is low, so strength is of only secondary importance in the Lockheed applications. Perhaps the second most important criterion is the ability of the alloy to resist corrosion in the environments in which the part will operate. The Dow 17 anodizing treatment has been found satisfactory for the parts manufactured to date at LMSC.

The activities at Lockheed have resulted in a number of internal reports and several published papers, all of which were made available for this survey.

The following types of applications for magnesium-lithium alloys have proven successful for Lockheed Missiles and Space Company:

(1) Electronic packaging
  (a) Fabricated boxes and covers for nonpressurized components
  (b) Deep-drawn boxes

(2) Mounting segments: angles, channels, hat sections, and Z sections

(3) Mounting clips for microwave guides

(4) Spun air-conditioning duct work

(5) Pressure and dust panels

(6) Antenna-mounting structures

(7) Gyro mounts

(8) Brackets for electronic connections

(9) Heat shields

Many of the parts that Lockheed has manufactured from the alloys have been used in successful space missions. Some examples may be seen in figures 1 through 7.

The base for the gyro-moment control, figure 6, was designed originally for fabrication from 0.060-inch beryllium sheet. The design was changed to use 0.125-inch sheet of magnesium-lithium alloy with a net saving in weight. The mount is approximately 18 inches long by 8 inches deep and 2½ inches thick. Lockheed personnel stated that the design had to be changed from beryllium to magnesium-lithium because fabrication difficulties with the beryllium threatened to prevent meeting the schedule of the vehicle. The part was fabricated readily from the magnesium-lithium alloy, and the vehicle was completed on schedule.

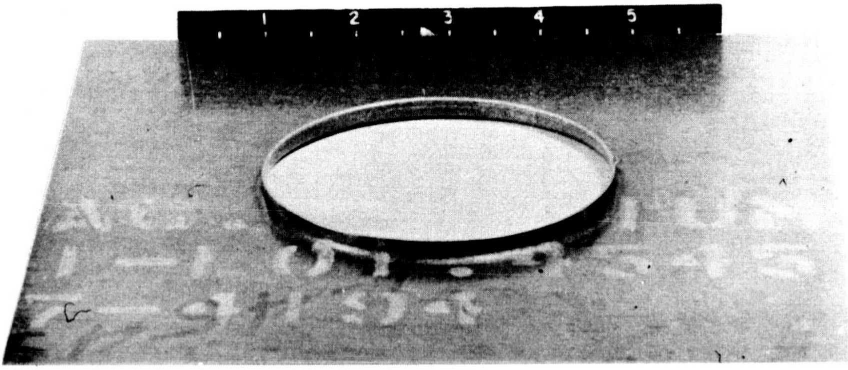

FIGURE 1.—*Hardware for NASA's EGO satellite. This represents Lockheed's early efforts with magnesium-lithium alloys.* (LMSC PHOTOGRAPH)

INTERNATIONAL BUSINESS MACHINES CORPORATION (IBM) FEDERAL SYSTEMS DIVISION

The Federal Systems Division of IBM has been very active, for about the same length of time as Lockheed, in applying magnesium-lithium alloys to fabricated aerospace components. Although Lockheed has generated a large background of data on the mechanical properties of LA141A, IBM has contributed extensively to the knowledge of cleaning, anodizing, sealing, and other surface treatments of the alloy for adhesive bonding, corrosion protection, and solderability.

Brooks and Perkins, Incorporated has been the principal source of magnesium-lithium alloys for IBM, but the quantity of material purchased is not available. Much of the material ordered by IBM has been thick plate, e.g., up to 31½ by 13½ by 5 inches. This material has been supplied in the as-cast condition or with very little rolling reduction. The plate has been used to develop a digital-computer housing for the Saturn V launch vehicle. A photograph of the housing, as machined from the solid billet, is shown in figure 8. A similar housing is being developed for a data adapter to be used in conjunction with the computer.

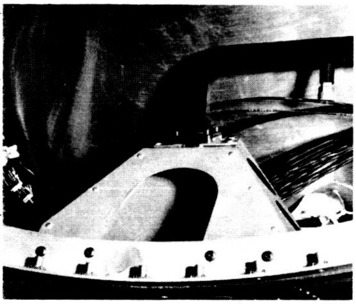

FIGURE 2.—*Microwave mount for Agena.* (LMSC PHOTOGRAPH)

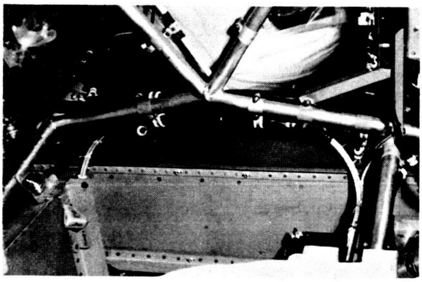

FIGURE 3.—*Dust panel, Agena.* (LMSC PHOTOGRAPH)

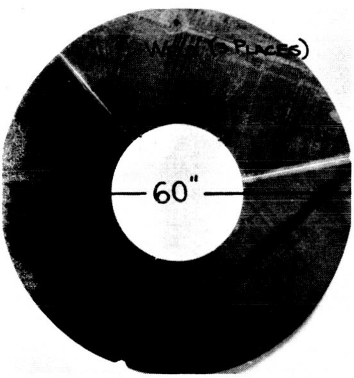

FIGURE 4.—*Pressure diaphragm for pay-load adapters used in Agena.* (LMSC PHOTOGRAPH)

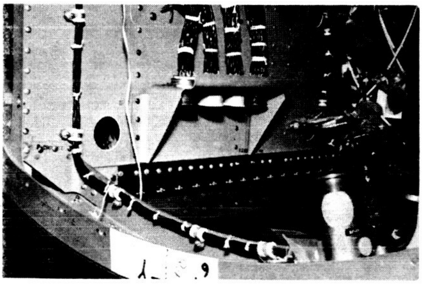

FIGURE 5.—*Magnesium-lithium electronic connector bracket originally designed for AZ31B-H24.* (LMSC PHOTOGRAPH)

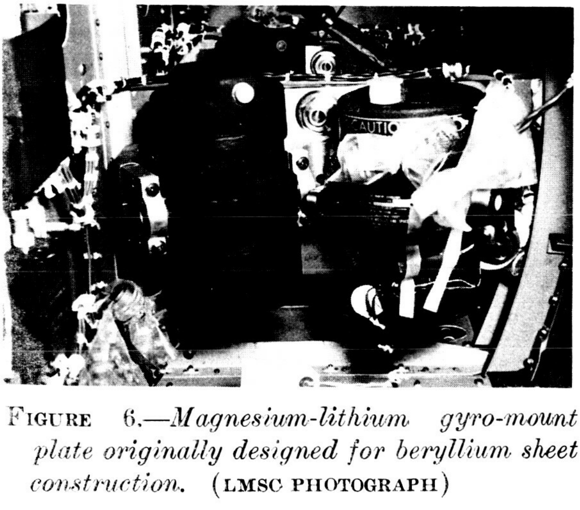

FIGURE 6.—*Magnesium-lithium gyro-mount plate originally designed for beryllium sheet construction.* (LMSC PHOTOGRAPH)

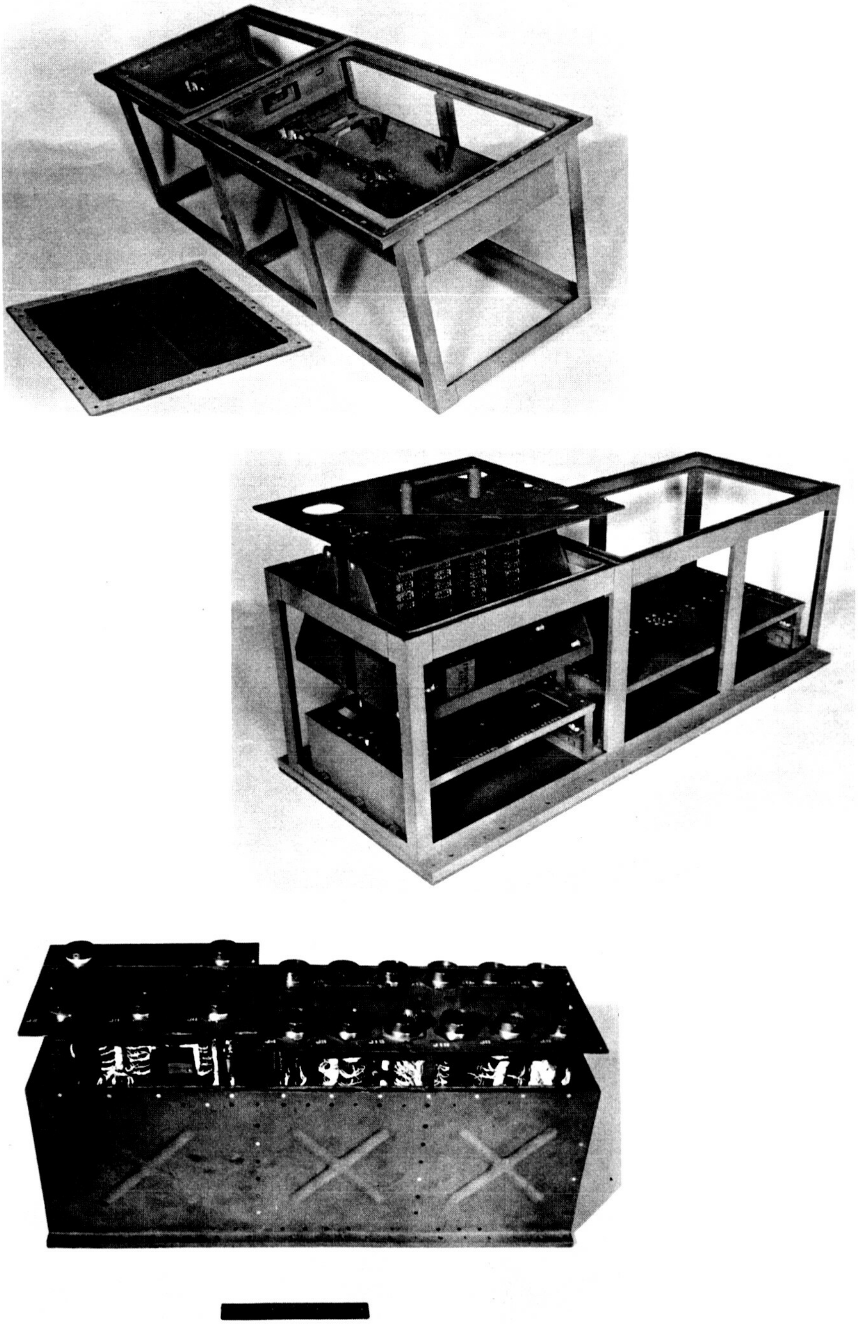

FIGURE 7.—*Sequential steps in the assembly of a magnesium-lithium power-control unit.* (LMSC PHOTOGRAPHS)

This application of the alloys, which comprises a large contract with NASA's Marshall Space Flight Center, is an ambitious one for the new material. The computer housing is precisely engineered. It must be internally cooled with a methanol-water solution, whereas other control equipment is cooled externally by conducting heat to a cold plate. In addition, it must withstand severe laboratory corrosion tests. If the magnesium-lithium computer can meet these requirements for the Saturn application, the results should encourage extensive usage of the alloys in other aerospace equipment.

Before the Saturn V project, IBM worked with the McDonnell Aircraft Corporation to develop LA141A alloy hardware for NASA's Gemini program. The circuit module covers shown in figure 9 were impact-extruded from LA141A sheet for IBM by the Zero Manufacturing Company, Burbank, California.

IBM also developed the Gemini manual data keyboard unit shown in figure 10. The base and support structure are LA141A. Note the welded construction.

DOW CHEMICAL COMPANY

This section is a brief abstract of the development of the M113 armored vehicle by the Dow Chemical Company and Food Machinery Corporation under contract DA–20–018–ORD–15739 with the U.S. Army Tank-Automotive Center, Detroit Arsenal (ref. 39).

Dow Chemical Company has been active in the investigation of magnesium-lithium alloys since about 1947 when the company started an extensive research and development program for the U.S. Army Research and Engineering Center, Fort Belvoir, Virginia. A review of this research and that performed by Dow on the alloys for other Government agencies is outside the scope of this report. However, the development of the M113 vehicle is a current application that grew out of Dow's research and, as such, is pertinent to this report.

The contract was awarded in 1957 to build a welded M113 vehicle hull following a modified design originally used for an aluminum alloy hull. The magnesium-lithium alloy Mg–13.5%Li–5.5%Al–0.15%Mn (LA136) was selected for the hull on the basis of fabrication and ballistic tests conducted by Armour Research Foundation* and Frankford Arsenal. Due to casting, corrosion, or fabrication problems with this alloy, the nominal composition was changed in 1959 to Mg–14%Li–1.5%Al–0.08%Mn, and all plates supplied for the hull were of the latter composition.

*Now Illinois Institute of Technology Research Institute.

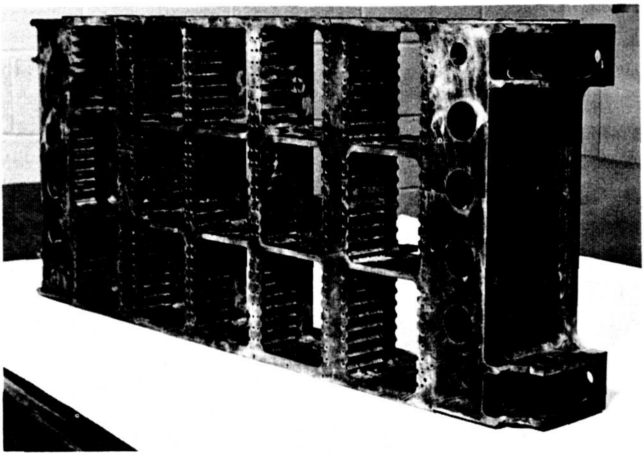

FIGURE 8.—*View of a Saturn V computer housing machined from a slightly rolled cast-slab of LA141A alloy. Small-diameter holes are gun-drilled through width and thickness of block for circulation of coolant. The part as shown is approximately 30 by 12 by 5 inches.* (IBM PHOTOGRAPH)

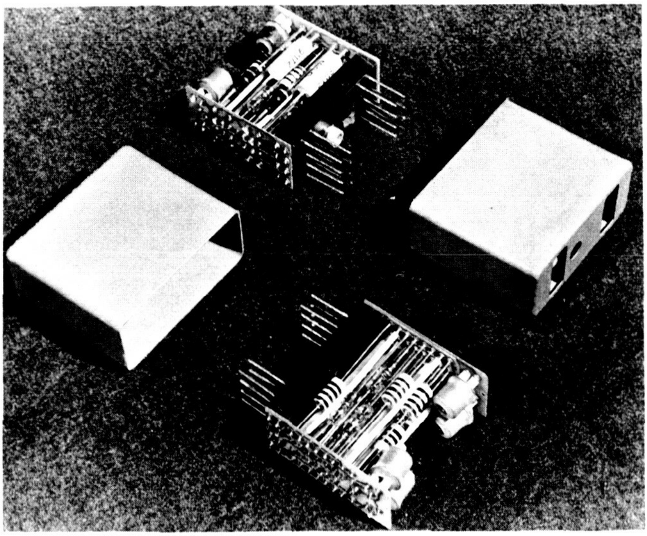

FIGURE 9.—*Circuit module covers impact-extruded from LA141A by the Zero Manufacturing Company for IBM's Gemini computer program.* (IBM PHOTOGRAPH)

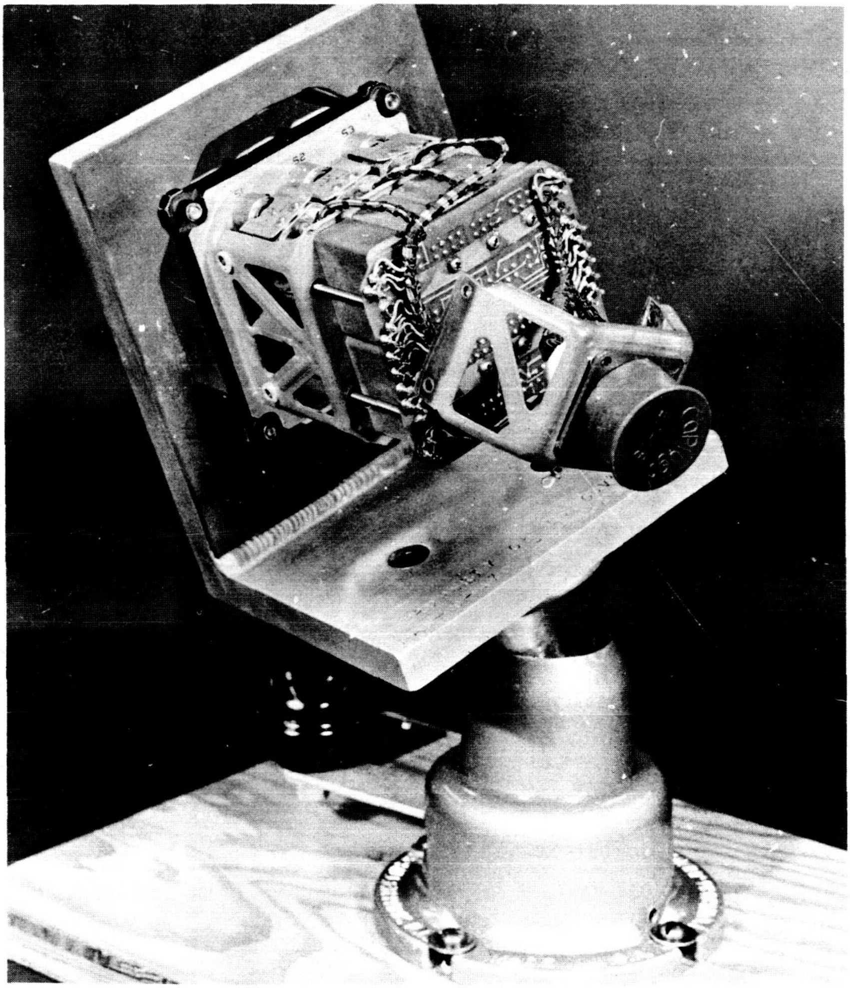

FIGURE 10.—*Gemini manual data keyboard developed by IBM for McDonnell Aircraft. The base and support structure are LA141A.* (IBM PHOTOGRAPH)

Melting and casting equipment, built at Dow's plant in Madison, Illinois, was capable of handling heats weighing about 4000 pounds. The flux used was 12.5%LiF–37.5%LiCl–50%KCl, its weight being about one-tenth the weight of the metal. Freon 114 was flushed through the mold to prevent burning. This action did not prevent oxidation, however, and oxide skins in the ingots were a problem. Melting losses of all metals were between 8 and 19 percent, depending on casting conditions.

The ingots cast were slabs measuring 11 by 27 by 86 inches. These

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were cropped and then scalped to an average depth of about ¾ inch on all surfaces to produce rolling slabs. They were rolled at 400° F to plate ranging in thickness from 3.0 to 0.5 inches. Oxide skins were sawed or routed out. About 20 000 pounds of metal were melted. Figure 11 shows the melting facilities; figure 12 a cast slab ingot.

Extensive welding studies were carried out by Dow to determine the best filler metal and welding procedures for thick plate of the alloy. It was concluded that argon-atmosphere welding by the MIG process, using AZ92A or AZ61A filler rods, without preheating, was satisfactory.

In 1958 fabrication of the vehicle was subcontracted to Food Machinery Corporation (FMC), San Jose, California. Plates for the hull were submitted to FMC in 1960, and the hull was completed in 1962. During the construction, many weld-cracking problems were encountered, due partly to voids and laminations in the plate, partly to stress corrosion, and partly to the necessity of developing suitable thermal-stress-relief treatments.

A stannate coating was developed by Dow and applied to the hull. The chief advantage of this treatment is that it simultaneously coats dissimilar metal inserts and fasteners with metallic tin and therefore suppresses corrosion. The stannate coating was followed by primer and coats of epoxy enamel paint.

Figure 13 is a view of the vehicle's hull being welded, and figure 14 shows the completed M113 armored personnel carrier.

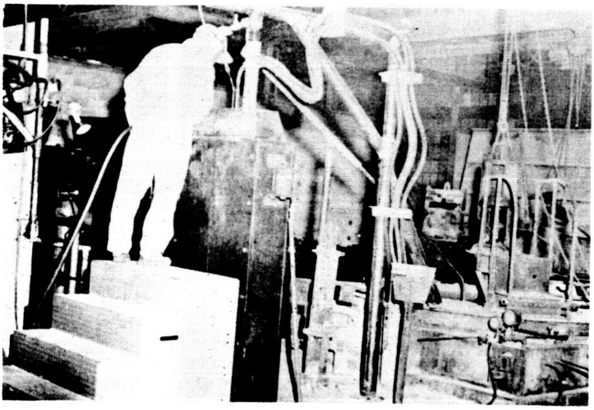
Some of the conclusions presented in Dow's final report (ref. 39) on the M113 vehicle are as follows:

(1) Experimental magnesium-lithium-aluminum alloys can be produced in heavy plate form. However, current technology does not permit casting of large slabs of the quality desired for ballistic plate use. Aluminum content of alloys containing 12.5%–15% lithium must be held between 1% and 2%, for satisfactory rolling and welding. Melting, casting, and scalping operations with magnesium-lithium alloys present more technical problems and require more safety precautions than do conventional magnesium alloys.

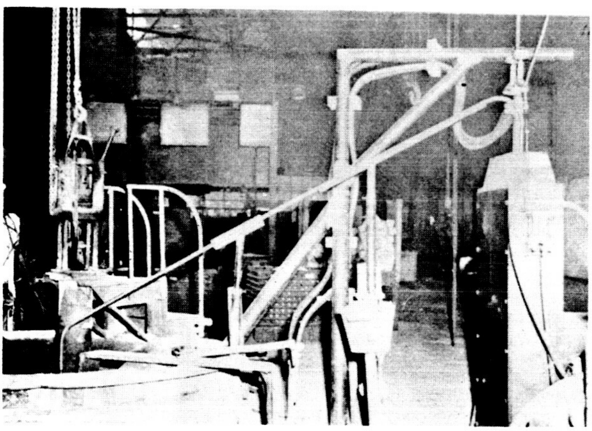
(2) Fabrication procedures for wrought magnesium-lithium alloys, such as sawing, machining, and welding, present no unusual problems, compared with conventional magnesium alloys. However, thermal stress relief must be used immediately after welding of restrained joints to prevent stress-corrosion cracking. Normal shop safety practices used with conventional magnesium alloys are sufficient for use with magnesium-lithium alloys.

(3) The stannate immersion process may be used as a prepaint treatment for magnesium-lithium alloys, in lieu of the Dow 17 anodize treatment. Wash primer plus epoxy paint systems may be used as protective coatings.

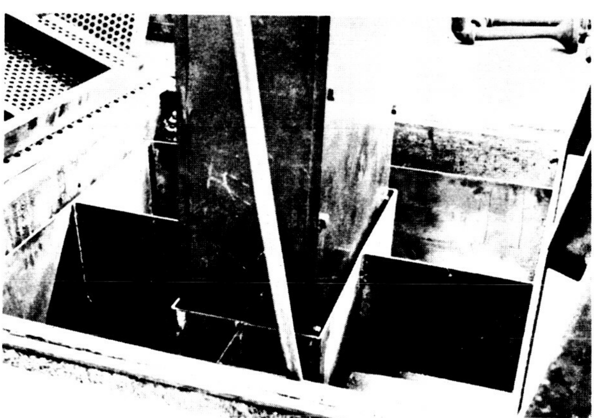
(4) While an experimental M113 vehicle hull has been fabricated from magnesium-lithium alloy plate, large scale production use in this type of vehicle does not seem feasible in the near future, because of problems in casting high-quality slabs, the requirement for immediate post-weld thermal treatment, and the relatively high cost of such alloys, due in part to the current cost of lithium.



a. Mold in position—metal caster controlling metal level.



b. Over-all view—pot, pump, casting line, bus connections, mold.



c. Floor plates removed showing runout pan.

FIGURE 11.—*Melting facilities installed at Dow's Madison plant to prepare magnesium-lithium ingots for M113 vehicle program.* (DOW METAL PRODUCTS PHOTOGRAPH)

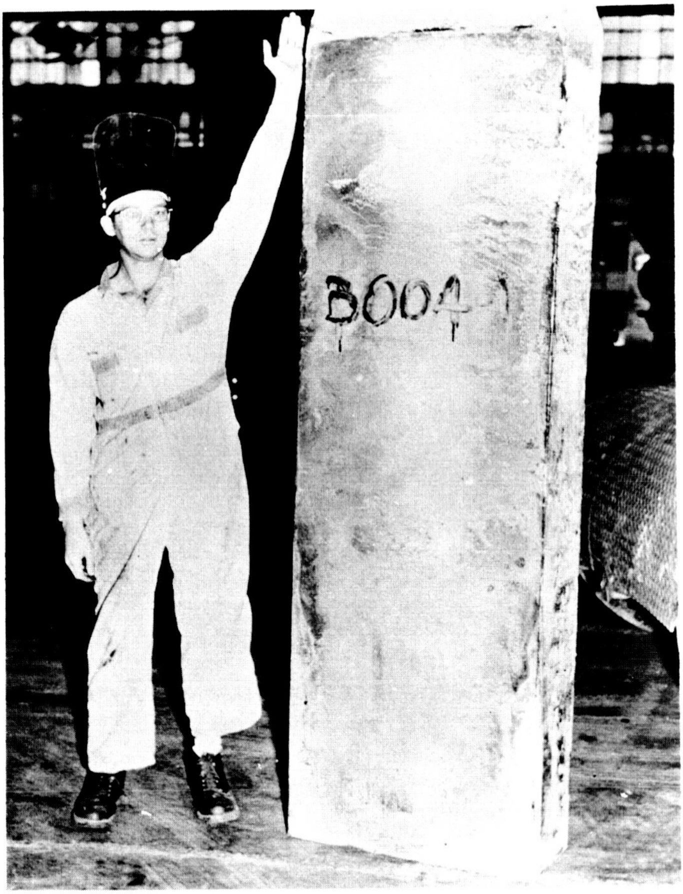


FIGURE 12.—*One of the cast 11-by-27-by-86-inch magnesium-lithium ingots.* (DOW METAL PRODUCTS PHOTOGRAPH)

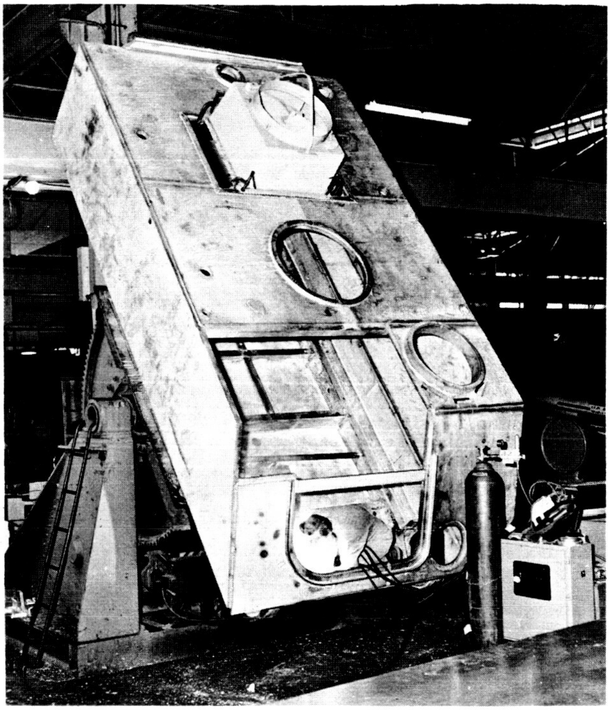


FIGURE 13.—*Photograph of the magnesium-lithium alloy-welded hull of the M113 vehicle.* (DOW METAL PRODUCTS PHOTOGRAPH)

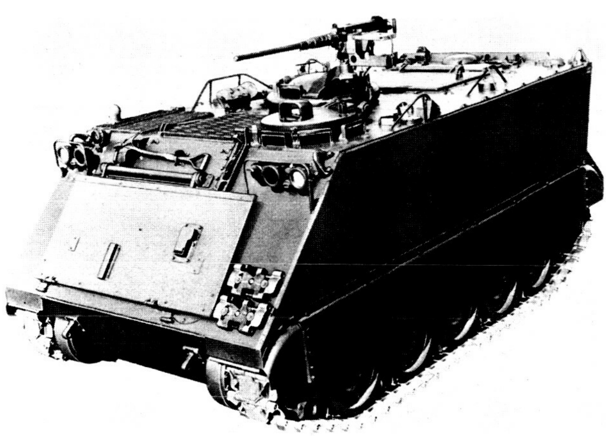


FIGURE 14.—*View of the completed M113 vehicle.* (DOW METAL PRODUCTS PHOTOGRAPH)

DETROIT TANK ARSENAL, ARMY TANK-AUTOMOTIVE CENTER (ATAC)

The activity of the Detroit Tank Arsenal with magnesium-lithium alloys has been described in the preceding section on the Dow Chemical Company. A visit was made to the arsenal to obtain information on the status of the M113 vehicle and plans for the future.

Road testing of the M113 vehicle having the magnesium-lithium alloy hull showed a noticeable improvement in handling and maneuverability over the heavier conventional-hull vehicles. During testing, cracks opened up in some of the welds, but they were not severe and did not become worse as the tests continued. The cracks did not affect the operation of the vehicle. In fact, it has been used since for several nonrelated testing programs at the arsenal.

The ATAC opinion of the magnesium-lithium material appears to be favorable in spite of the quality and fabrication problems encountered in the development of the M113. ATAC is not considering the alloy for any current applications, probably due to a number of factors. First, the alloy is expensive. Second, armor-piercing projectile resistance is considered to be equally as or more important than fragment resistance, and it is the latter for which the magnesium-lithium alloys are outstanding. Third, research efforts on new materials are being directed toward composites, which in laboratory tests show better ballistic properties than solid materials. Fourth, while there is a trend toward reducing the weight of armored vehicles, it is equally or more important to reduce the size.

These and other factors governing the development and application of armor are subjective, to say the least. However, conversations held with personnel at ATAC, Frankford Arsenal, and Watertown Arsenal indicate that it is unlikely that these organizations will renew any extensive development of magnesium-lithium armor in the near future.

BATTELLE MEMORIAL INSTITUTE

Battelle started the research on magnesium-lithium alloys in this country in 1944 and has had a nearly continuous research activity with them since that date. A review of this research is outside the scope of this report. However, it covered the development of melting and fabricating methods, the discovery and intensive study of the precipitation-hardening mechanism and alloy development, and the evaluation of alloys for aerospace usage. Early research, conducted for Mathieson Alkali Works (now Olin Mathieson) and the U.S. Naval Bureau of Aeronautics (ref. 19) led to the development of the basic armor alloys 6Mg/Li–6%Al (Mg–13.5%Li–6%Al) and 6Mg/Li–1.5%Al (Mg–14%Li–1.5%Al), which were later evaluated and used for the M113 vehicle by Dow Metal Products Company and Frankford Arsenal.

The latter alloy was the approximate nominal composition adopted for LA141A. It was evaluated for possible aerospace use by Battelle under contract to NASA from 1957 to 1960 and was recommended to the aerospace industry for space-hardware applications (ref. 31). More recently Battelle examined a new composition, LAZ933, for possible aerospace use. This is described in the section on the Marshall Space Flight Center.

FRANKFORD ARSENAL

The Pitman-Dunn Laboratory at Frankford Arsenal has maintained an active program on magnesium-lithium alloys since the early 1950's. Basic research supported by Frankford at the Illinois Institute of Technology (IIT) Research Institute during that period resulted in several published papers on phase relationships in the Mg-Li-Al and Mg-Li-Zn systems (refs. 14, 16, and 17). Frankford later sponsored alloy development work at IIT Research Institute in connection with the ATAC M113 vehicle program.

More recently the Pitman-Dunn Laboratory has been supporting an internal research program on alloy development and casting process development (refs. 34 and 40).

The Frankford Arsenal research has led to several significant developments. Two new alloy compositions have been developed to the point where small-scale evaluation tests are being conducted. The alloys have the following nominal compositions: Mg-14%Li-0.5%Si and Mg-14%Li-3%Ag-5%Zn-2%Si. Some properties of the first alloy are given in table 2. This alloy does not respond to heat treatment but has room-temperature strength comparable with that of the LA141A alloy.

TABLE 2.—*Some Room-Temperature Tensile Properties of the Experimental Mg-14% Li-0.5% Si Alloy Under Development at Frankford Arsenal*

Days at 225° F	Cast alloy		Wrought alloy	
	UTS, lb/in²	% elongation	UTS, lb/in²	% elongation
0	19 750	23	19 800	32
5	19 520	26	19 900	33
14	19 900	23	20 100	33
30	19 700	23	20 000	35
80	19 750	23	20 200	35
Density of the alloy = 0.048 lb/in³				

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The second alloy, Mg-14%Li-3%Ag-5%Zn-2%Si, has higher strength, as shown in table 3. The silicon addition permits the Mg-Li-3Ag-5Zn alloy to retain a higher strength level during the 80-day period at 165° F. The density of the Mg-Li-Ag-Zn-Si alloy is 0.054 lb/in^3.

TABLE 3.—*Frankford Arsenal Data Showing Effect of Aging (165° F) on Tensile Properties of Heat-Treated* Mg-14Li-3-AG-5Zn-Type Alloys*

Days	Mg-14Li-3Ag-5Zn				Mg-14Li-3Ag-5Zn-2Si			
	Cast		Wrought		Cast		Wrought	
	UTS, lb/in ^{2}	Elon. %	UTS, lb/in ^{2}	Elon. %	UTS, lb/in ^{2}	Elon. %	UTS, lb/in ^{2}	Elon. %
5	26 500	12.0	27 650	29.5	29 300	5.0	29 050	30.0
14	25 500	10.0	26 200	37.5	29 300	5.0	28 750	31.5
30	24 100	15.0	25 700	38.0	28 900	5.0	28 750	31.5
80	24 000	16.0	25 600	38.0	29 000	5.0	28 750	31.5

*Cast: heat-treated at 800° F for 4 hr, water-quenched for 24 hr at 225° F. Wrought: 24 hr, 225° F.

The silicon in these alloys produces a marked grain refinement.

The arsenal has experimented with the casting of magnesium-lithium alloys in steel, machined graphite, rammed graphite, and sand molds. Figure 15 is a photograph of a part made from a previously existing pattern. The mold material was rammed graphite. This casting research was recently supplemented by funds from NASA's Marshall Space Flight Center to permit the casting of prototype housings for electronic components in the magnesium-lithium-silicon alloy.

MARSHALL SPACE FLIGHT CENTER, NASA

The George C. Marshall Space Flight Center is the only NASA agency known to be actively engaged in research and application studies on magnesium-lithium alloys at the present time. This activity dates back to late 1957 when the Research Projects Office initiated the first research contract on the alloys at Battelle. The contract was continued under the supervision of the Propulsion and Vehicle Engineering (P&VE) Laboratory. The final report of the 2-year project was issued early in 1960 (ref. 31). In June 1962, the P&VE Laboratory resumed sponsorship of research on the magnesium-lithium alloys at Battelle, and the work continued until May 1964 (refs. 37 and 38).

Essentially, the research comprised the screening of magnesium-lithium alloy compositions made in previous years and the selection and evaluation of the compositions that would have the greatest potential use in aerospace applications. The three alloys selected had the following nominal compositions: Mg-14%Li-1%Al(LA141A), Mg-9%Li-1%Al(LA91), and Mg-9%Li-3%Al-3%Zn(LAZ933).

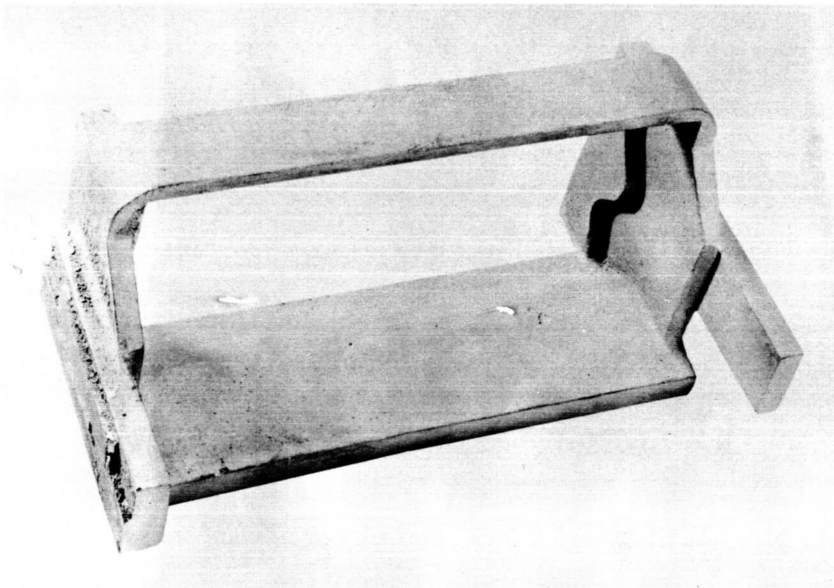

FIGURE 15.—*Instrument housing cast in rammed graphite from magnesium-lithium alloy.* (FRANKFORD ARSENAL PHOTOGRAPH)

The first alloy is the only one that has been produced on a commercial basis. LA91 has properties quite similar to those of LA141A, but it has a somewhat greater density. LAZ933 has a higher strength-to-weight ratio than the other alloys. Neither LA91 nor LAZ933 has been evaluated to the extent that engineering and design data are available. Table 4 is a summary of some of the properties of these two experimental alloys.

During the last several years, the P&VE Laboratory has maintained a modest but continuing in-house activity on the magnesium-lithium alloys. This has comprised evaluation studies of mechanical properties at ambient and cryogenic temperatures, weldability, corrosion resistance, reactivity in liquid oxygen and other environments, and other research.

The staff members who have had the responsibility for the magnesium-lithium alloy research have sought applications for them in NASA aerospace hardware. In 1964 this activity and more recent efforts of personnel in the Astrionics Laboratory led to an extensive program to make effective use of the alloys. A large order for sheet and plate was placed with Brooks and Perkins early this year for in-house manufacturing research. The Astrionics Laboratory is heavily committed to the use of LA141A in its contract with IBM on the computer and data adapter for the Saturn V program. A contract was recently initiated by the P&VE Laboratory with Frankford Arsenal for the development of castings for electronic-equipment housings.

TABLE 4.—*Some Properties of Experimental Alloys LA91 and LAZ933*

	LA91	LAZ933
Structure	H.C.P. plus B.C.C.*	H.C.P. plus B.C.C.
Density, lb/in³	0.0525	0.0564
Tensile strength, lb/in²	22 000	30 500
Yield strength, lb/in²	16 500	21 500
Elongation, percent in 2 in	30–35	35
Hardness, R_E	55	79
Minimum bend radius:		
Room temperature	1T	3T
350° F	1T	1T
Modulus of elasticity, 10^6 lb./in²	6.6	6.4

*H.C.P. indicates hexagonal-close-packed atomic lattice; B.C.C. indicates body-centered-cubic atomic lattice.

The LA141A alloy is being substituted for aluminum or magnesium in several structures under development by the Astrionics Laboratory. The first components, which are expected to fly in the number-9 bird of the Saturn IB program, are a housing and cover plate for an instrumentation assembly. The assembly, referred to as a "Q-ball, angle of attack transducer assembly" will be located in the nose cone of the system. Eventually, if the assembly is successful in Saturn IB trials, it will be used in the Saturn V nose cone in conjunction with the Apollo capsule.

The cover plate, as machined from a solid plate of LA141 alloy, is shown in figure 16. This part is a direct substitute for an aluminum casting. The weight saving is as follows:

	Weight, lb
Aluminum casting	2.8
LA141A machined part	1.5
Weight saved	1.3 lb or 46%

A saving of 1.3 pounds in any payload is most significant. The saving will be greater, of course, if the housing is also made from LA141A.

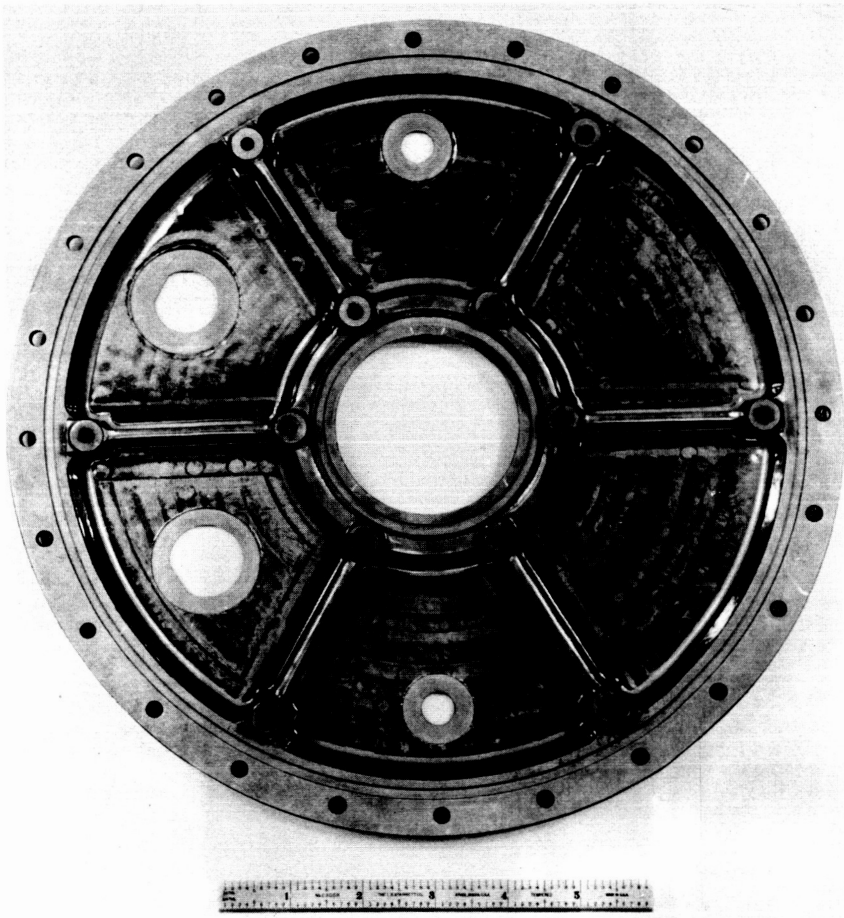

FIGURE 16.—*Cover of the Q-ball assembly being developed by NASA for use on Saturn IB and Saturn V.* (MARSHALL SPACE FLIGHT CENTER PHOTOGRAPH)

MASSACHUSETTS INSTITUTE OF TECHNOLOGY (MIT) INSTRUMENTATION LABORATORY

The MIT Instrumentation Laboratory at Concord, Massachusetts, in using the experimental Frankford Arsenal alloy Mg-14%Li-3%Ag-5%Zn-2%Si in the construction of a prototype inertial-guidance system. The specific parts being made in the magnesium-lithium alloy are three spherical gimbals about 9 inches in diameter, one of which is shown in figure 17. The gimbals were spun from flat ¼-inch plate. Spinning was done by Metal Spinners, Inc., Boston. The sheet was heated to about 200° F and formed over a steel mandrel. No problems were encountered. The spheres were then machined at Brooks and Perkins to a wall thickness of about $\frac{1}{16}$ inch. The band around the equator is about $\frac{3}{16}$-inch thick.

Because the gimbals will be floated in a hydrocarbon liquid system to reduce loading, problems have arisen in selecting coatings that will not absorb or react with the fluid. The uncoated alloy is more compatible than plastics, but it does gain weight over a period of 1 year when in contact with the fluid at 150° F. Compatibility was improved with a Dow 17 coating, but a completely inert system had not been found at the time of the interview for this report.

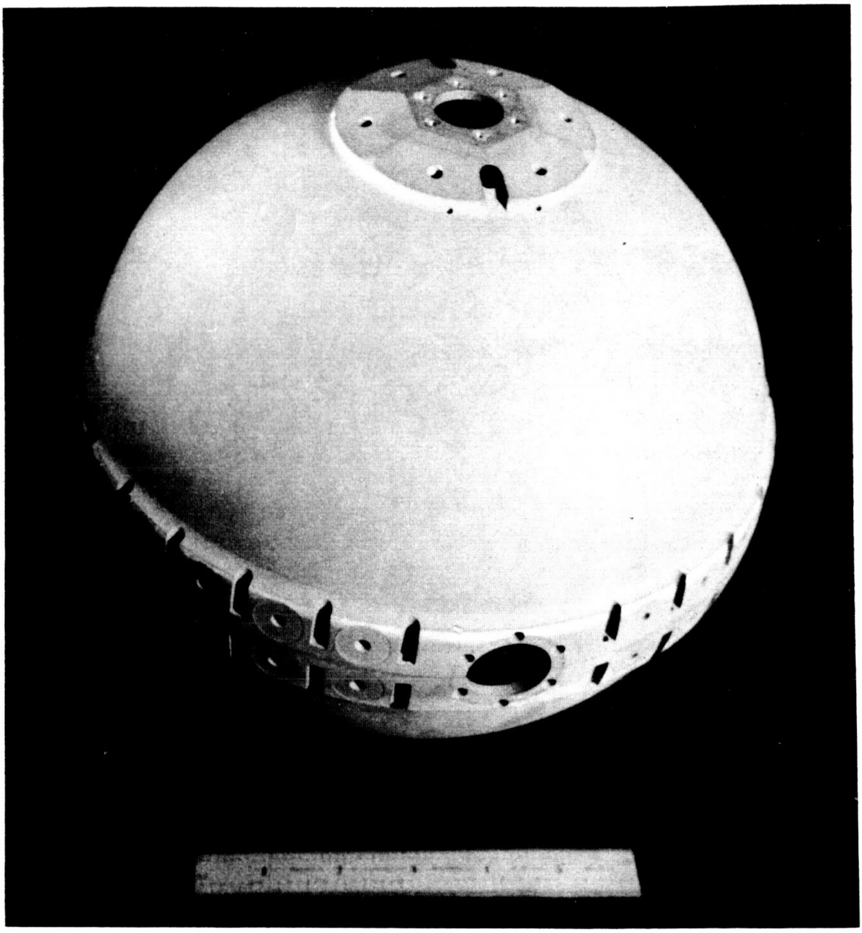

FIGURE 17.—*Spherical gimbal—one of three to be used in an advanced inertial-guidance system. A magnesium-lithium alloy was specified for minimum weight and maximum stiffness.* (MIT INSTRUMENTATION LABORATORY PHOTOGRAPH)

HUGHES AIRCRAFT COMPANY SPACE SYSTEMS DIVISION

Hughes Aircraft Company has a contract with the U.S. Army Missile Command to develop TOW (tube-launched, optically-tracked, wire command) link-guided missiles. A photograph of a model is shown in figure 18. The ground-to-ground missile, which seeks its target by an infrared sensing device after launching, must first be aimed as accurately as possible toward the target. This is done manually. To minimize "hunting" by the operator as he aims the launcher, a drag is imposed on the aiming mechanism by a metal disk that rotates in a silicone fluid inside the vertical support cylinder. The clearance between the cylinder wall and the periphery of the disk is small; the friction between the disk, the wall, and the silicone creates the desired drag.

LA141A alloy is being considered for the disk material for two reasons. First, it has a high coefficient of thermal expansion, which is necessary for controlling the wall clearance as ambient temperatures change. Second, it will reduce the weight of the launcher which, as designed for aluminum, weighs less than 160 pounds. Figure 19 is a photograph of two of several LA141A disks machined by Brooks and Perkins for this application.

ZERO MANUFACTURING COMPANY

Located in Burbank, California, Zero Manufacturing Company has been supplying IBM and Lockheed with deep-drawn or impact-extruded boxes made from LA141A sheet. A photograph of the impact-extruded circuit module covers made for IBM was shown earlier (fig. 9). Several thousands of these, or comparable parts, have been made.

The company reports that the drawing properties of LA141A are similar to those of AZ31B–0 annealed magnesium. Production and setup costs are said to be significantly higher than for magnesium, due to the necessity of controlling temperature more precisely. The maximum thickness of magnesium-lithium alloy sheet drawn to date is 0.063 inch. In this case the box was about 5 inches square by 4 inches deep and had corner and edge radii of $\frac{3}{16}$ inch.

The company also reports that LA141A flows better than AZ31B–0 but is not dimensionally stable after forming. The reason for the instability is not known, but allowance is made for some swelling of a part when very close tolerances, i.e., ± 0.002 inch, are called for. Rejection rates on close-tolerance, thin-wall impact extrusions (0.015 inch and under) are very high, but heavier-wall units experience a normal scrap rate.

FIGURE 18.—*Model of TOW (tube-launched, optically tracked, wire command) link-guided missile.* (HUGHES AIRCRAFT PHOTOGRAPH)

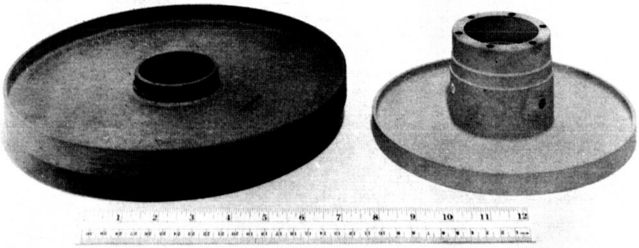

FIGURE 19.—*LA141A-alloy components made for evaluation in prototype missile launcher TOW.* (HUGHES AIRCRAFT PHOTOGRAPH)

The company feels that neither material thickness nor size of part needs to be a deterrent in the drawing or impact extrusion of LA141A alloy.

WELLMAN BRONZE AND ALUMINUM COMPANY

Wellman Bronze has successfully sand-cast LA141A alloy into the rotor part shown in figure 20. This part was made because the pattern was available, not for a specific application. At the time of the visit, Wellman had just received a contract from IBM to make some larger castings having heavier sections.

The company has melted heats weighing up to 40 pounds by using the LiCl-LiF flux process. Melt sizes are adjusted so the lithium can be added in sealed cans. Heats are poured through steel wool and wire screens, as is done with magnesium alloys.

Wellman does not visualize any commercial applications for the alloys in the near future and has no plans to go into the magnesium-lithium business.

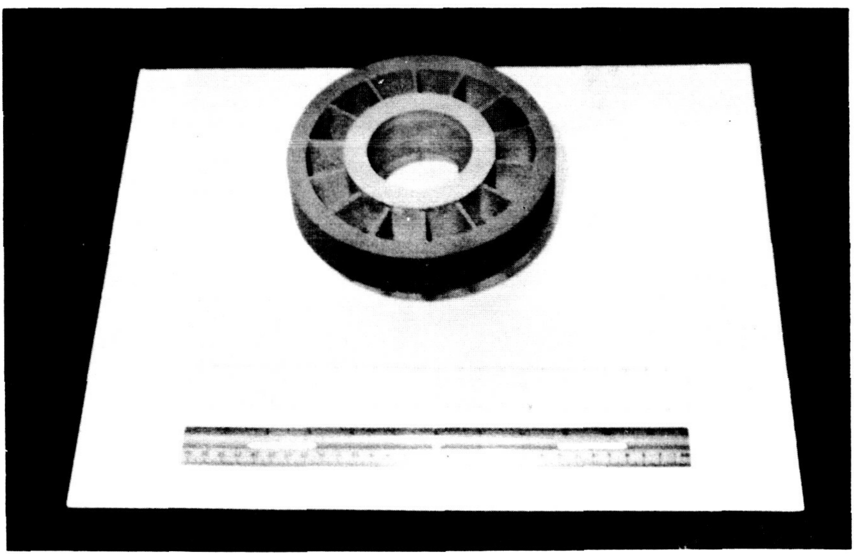

FIGURE 20.—*Rotor made as a sand casting from LA141A alloy.* (WELLMAN PHOTOGRAPH)

NORTH AMERICAN AVIATION, INC. AUTONETICS DIVISION

The Autonetics Division is investigating magnesium-lithium alloys for several parts of the inertial guidance and control system of the advanced Minute Man. Because of security restrictions not all of these parts can be discussed. However, one part of considerable interest is the accelerometer housing shown in figure 21. This container, which is about 15 inches in diameter by about 24 inches in height, houses the entire stable platform. The construction is cold-formed 0.030-inch LA141A sheet, riveted and bolted together. No trouble was encountered in forming the sheet. The surface is protected by Dow 17 anodic coating, which will be adequate for the dry nitrogen environment. This guidance system will weigh about one-third as much as the present system in operational Minute Man missiles.

Autonetics is working on protective treatments for magnesium-lithium alloys to obtain adequate protection to meet the stringent requirements specified by MIL–E–5272 for thermal cycling in a high-humidity atmosphere.

FIGURE 21.—*Accelerometer housing for the advanced Minute Man, fabricated from 0.030-inch LA141A sheet.* (NORTH AMERICAN AVIATION PHOTOGRAPH)

SANDIA CORPORATION

The Sandia Corporation at Livermore, California, has ordered heavy LA141A plate from Brooks and Perkins for cover plates to be used in a classified prototype application. The covers will be roughly 20 inches in diameter, 4 inches deep, and 1 inch thick at the heaviest section. Sandia has specified that the material be in the wrought condition because as-cast properties would not be good enough. To obtain a casting thick enough to forge, it is understood that Brooks and Perkins has made new molds.

The covers will be coated with some protective medium not yet selected, and the outside surface will require the application of adhesive bonding. Sandia is experimenting with various protective coatings and methods for adhesive bonding.

GENERAL ELECTRIC COMPANY
MISSILE AND SPACE VEHICLE DEPARTMENT

General Electric is evaluating LA141A for several proposed aerospace equipment designs. No information was made available on the nature of the applications or on the evaluation activities, except that the alloy is of interest for its high modulus-to-density ratio and would be used for reinforcements and space fillers.

BOEING COMPANY
AERO SPACE DIVISION

Boeing is considering the use of magnesium-lithium alloys in nonstressed components of the Lunar Orbiting Satellite. Samples of the LA141A alloy are being evaluated, but no hardware has been made. The alloys are also being considered in study programs in progress for space vehicles such as the Manned Orbiting Laboratory and the Lunar Mobile Laboratory.

THOMPSON RAMO WOOLDRIDGE, INC.
SPACE TECHNOLOGY LABORATORIES (STL)

A visit was made to STL because of the interest expressed in the magnesium-lithium alloys by the technical staff. The company has no magnesium-lithium alloy hardware in production at this time, but is considering the material for the Pioneer spacecraft and other vehicles. A limited amount of LA141A sheet has been procured for welding, coating, and other evaluation studies.

Aluminum is now used in the construction of the Pioneer, but STL plans to use magnesium in the future. STL is not tooled up for hot-forming magnesium, which has been a deterrent. The technical staff is concerned also about corrosion problems with magnesium. Integration problems are said to be greater in satellite manufacture than in booster manufacture because of lower production, more numerous changes, and so on. Despite the problems anticipated by the staff, it is quite likely that magnesium-lithium alloys will be used in the newer STL vehicles.

ACTIVITIES IN THE U.S.S.R.

Since F. I. Shamrai's publications in 1947, 1948, and 1952 (refs. 5 and 11), there has been little information published on U.S.S.R. activities on magnesium-lithium alloys. Of the other Russian publications referenced in this report (refs. 28, 35 and 36), the most significant from the application standpoint is reference 28, a paper by Belousov and Yegorova on die-casting of the magnesium-lithium alloys. These authors refer to the publication by J. H. Jackson et al. (ref. 6), and they used the melting methods described in this publication.

The Russian investigators tried making sand castings but ran into difficulty with reaction between the metal and the sand molds. They cast successfully into iron molds and improved the ingot surfaces by applying pressure to the metal during freezing, which sealed the ingot surface from the air and avoided oxidation. The several alloys investigated are shown in table 5.

TABLE 5.—*Alloys Investigated by Belousov and Yegorova*

Alloy	Lithium	Aluminum	Zinc	Magnesium
1	9	3	8	Balance
2	9	6	3	Balance
3	10	--------------	--------	Balance

Belousov and Yegorova then made experimental die castings from these alloys in a Reid-Prentice type of casting machine. These were compared with castings of a standard magnesium ML6–type die-casting alloy. (ML6—type corresponds to AZ91. It has 9–10.2% Al, 0.6–1.2% Zn, and 0.1–0.5% Mn.) The castings are shown in figure 22.

Blow holes typical of die-cast parts were found in the castings by fluoroscopic examination. These were less prevalent in flat tensile specimen castings than in cylindrical sections. Tensile bar castings were tested in the as-cast and heat-treated conditions.

It was concluded that the magnesium-lithium alloys will be satisfactory for die castings in which the design calls for strength equal to that of standard magnesium alloys but with densities in the range of 1.45 to 1.65 g/cm^3.

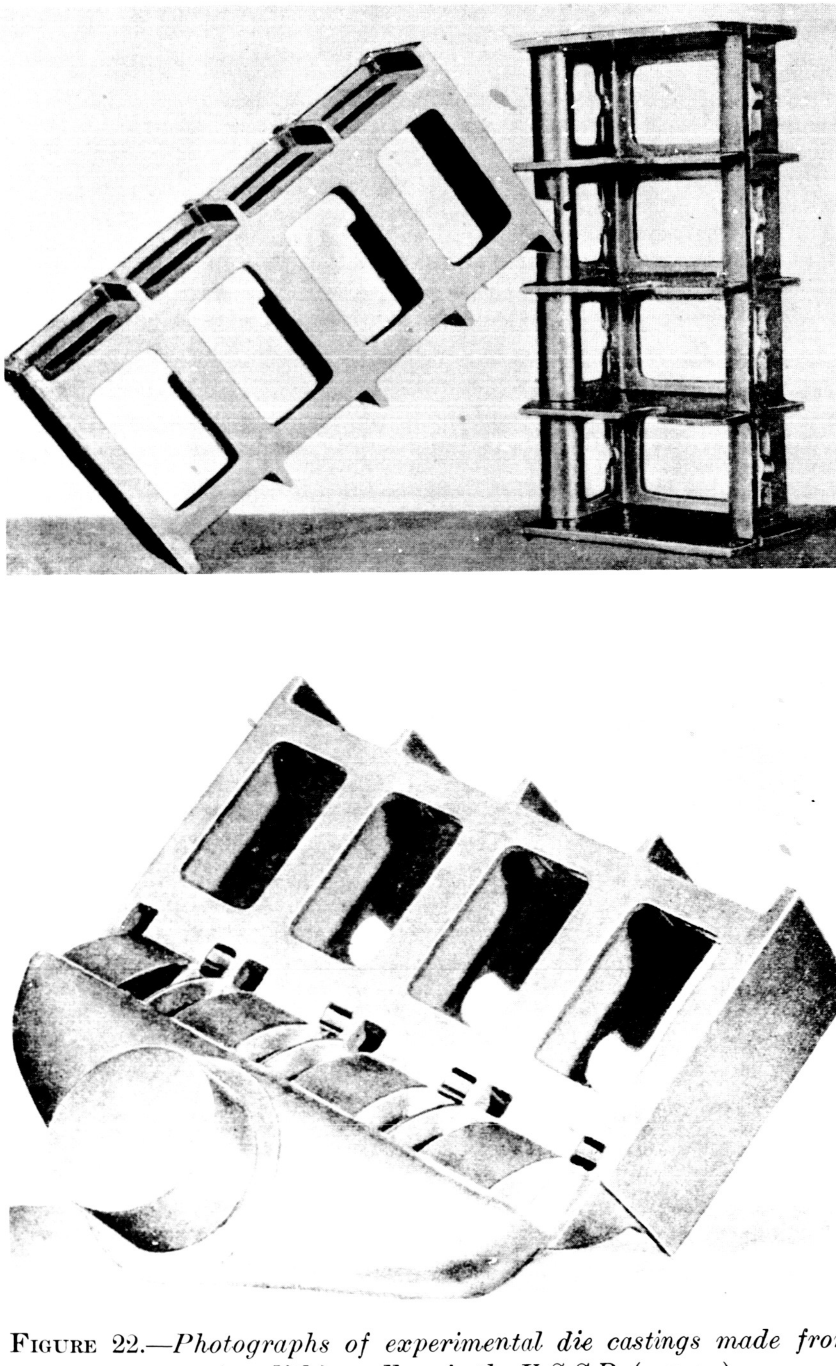

FIGURE 22.—*Photographs of experimental die castings made from magnesium-lithium alloys in the U.S.S.R.* (REF. 28)

Savitskii et al. (ref. 36) examined several cast and wrought alloys. The authors concluded that ternary alloys containing from 7 to 15 percent aluminum, 15 to 25 percent lithium, and 60 to 80 percent magnesium ". . . can be recommended for structural alloys. They can find use in different technical areas where operation specifics require a reduction in the specific gravity of structures."

Economics

COMMERCIAL PRODUCERS OF MAGNESIUM-LITHIUM ALLOYS AND PRESENT PRICE SCHEDULES

The only producer of the alloys in the United States is Brooks and Perkins (B&P), Inc., Detroit. This company has facilities for melting and casting conventional magnesium alloy and magnesium-lithium alloy ingots; it has rolling mills for flat products of these alloys and aluminum and titanium alloys; and it has extensive facilities for forming, machining, and finishing end products from all of these materials.

The casting and rolling facilities at B&P are occupied for the most part by conventional magnesium alloys; magnesium-lithium alloys comprise a relatively small part of the production. In comparison, the B&P facilities for mill products are much smaller than those of the Dow Metal Products Company.

The alloy LA141A is currently being sold by Brooks and Perkins for $10 to $50 per pound, depending on the mill product. Slab ingots, cropped and machined on all surfaces, sell for a minimum of $10 per pound; plate and thin sheet, ranging in thickness from over 1 inch to foil, command the prices in the higher range. B&P has no standard mill forms; all orders are filled on a custom basis because the number of customers is small and each customer has different requirements.

The only other producer for magnesium-lithium alloys at this time is Magnesium Elektron, Limited (MEL), Manchester, England, which has an American sales subsidiary, Magnesium Elektron, Inc., in New York City. MEL has smaller mill facilities than Brooks and Perkins and produces magnesium-lithium alloys on a very small scale on custom orders. Since there is little aerospace industry in Europe or England, there have been almost no orders from that source. The company has received from the United States a few orders that have included cast plate, sheet, and welding rod. These orders, estimated not to exceed a few hundred pounds, have been for experimental uses only. Due to the import duty, MEL does not expect the business to grow in competition with Brooks and Perkins.

Conversations with Dow Metal Products Company personnel concerning the possibility of Dow's becoming a commercial producer indicated that there is no interest as long as (1) the alloys are available from Brooks and Perkins and (2) the market remains small enough that one producer is adequate. Just how large the market would have to be to interest Dow cannot be determined at this time.

PRESENT CONSUMPTION OF MAGNESIUM-LITHIUM ALLOYS

Although the primary objective of this report was not to conduct a market study, information became available as a matter of course concerning the quantities of magnesium-lithium alloy mill products being used and the portions of the market shared by the two alloy suppliers.

As was believed to be the case, present production is consumed almost entirely by a few organizations in the aerospace industry. Of these, the Lockheed Missiles and Space Company and International Business Machines, Federal Systems Division, are by far the principal industrial customers. NASA's Marshall Space Flight Center became a third major customer this year, and a number of other aerospace organizations that have not yet placed large orders are expected to do so in the near future.

On the basis of information gathered from interviews with the producers of the alloy, the several American companies that supply lithium, and the organizations that are using the alloys, the following estimates were made for consumption of magnesium-lithium alloys in the United States:

Year	*Sheet and plate sold*
1962	2 000 lb
1963	8 000 lb
1964 (first 6 months)	11 000 lb

Small quantities of magnesium-lithium alloys were made for experimental studies during these years by the Dow Metal Products Company, Battelle Institute, and Frankford Arsenal. These are not included in the above estimates. The estimate for the first 6 months of 1964 includes one very large order received by Brooks and Perkins from NASA-Huntsville; therefore, the figure does not necessarily indicate what will happen during the rest of the year.

Essentially all of the products sold during these years have been ingot, plate, and sheet although a few extrusions have been made and sold. Only a few shaped castings have been made for research and development purposes at Frankford Arsenal and the Wellman Bronze and Aluminum Company.

It was not possible to estimate accurately the dollar value of the present mill-product market. If it is assumed that the average selling price is about $25 per pound, this would indicate a gross sales volume of about $200 000 in 1963 and $275 000 in the first 6 months of 1964.

FACTORS AFFECTING THE PRESENT USAGE OF MAGNESIUM-LITHIUM ALLOYS

The factors that usually influence the usage of a new alloy are (1) the cost of the metallic elements in the alloy, (2) manufacturing costs for melting and fabricating mill products and end products, and (3) the properties of the alloy.

For example, titanium alloys are coming into wider use partly because the cost of the raw metal sponge is low compared with its cost 15 years ago. At the same time, there has been a steady decrease in manufacturing costs for mill products and end products as people have learned to work with the metal. The outstanding properties of high strength, low weight, and good corrosion resistance create considerable incentive for lower production and fabrication costs for titanium. In spite of excellent progress to date, the material will be a defense-oriented rather than a commercially-oriented metal for some years.

Beryllium raw-material costs are high, but because of its brittleness, fabrication costs several times more than the raw material. This problem, which is both technical and economic, is restricting the use of beryllium in the space industry.

In the case of magnesium-lithium alloys, the raw-materials cost is high because of the lithium content. The fabrication costs for end products of magnesium-lithium alloys are in line with those for aluminum and conventional magnesium alloys. However, the costs of melting and fabricating mill products from the alloys are high because (1) present melting methods are not optimum and generate a large percentage of scrap metal and (2) the low volume of current production requires high-cost, unautomated manufacturing methods. Regarding properties, the magnesium-lithium alloys do not have high strength or good corrosion resistance. Thus, they do not have the universal appeal and potential usefulness that titanium has. However, the low density of the magnesium-lithium alloys makes them unique. For this reason alone, they are almost certain to be used widely providing their price can be reduced. The factors that affect magnesium-lithium alloy prices are discussed in greater detail in the following sections.

Production Volume

A new material is rarely, if ever, placed on the market at as low a price as it will have after a number of years of production. Most materials become less expensive as production volume increases, and the magnesium-lithium alloys are no exception.

Although it is difficult to generalize, the cost of a metal mill product can be expected to be two to four times the cost of the raw materials in the alloy. For example, aluminum sheet sells for about $0.45 per pound as compared with the ingot price of $0.23 per pound; magnesium alloy sheet sells for approximately $1.00 per pound as compared with $0.35 per pound for pig; copper sheet and tube sell for around $0.60 per pound as compared with $0.32 per pound for electrolytic copper. The current prices for magnesium-lithium sheet do not conform to this relationship; they cannot be expected to do so with the present volume and method of production.

The LA141A alloy is now being made in special, low-capacity melting equipment by essentially a hand-operation process. Melting and rolling must be done on a part-time basis, sandwiched between the rolling of other materials. This low rate of production does not account entirely for the present prices of the alloy, but it is undoubtedly the most important single factor.

Raw-Materials Cost

The principal suppliers of lithium metal are Foote Mineral Company and the Lithium Corporation of America. The other two U.S. suppliers are the American Potash and Chemical Corporation and the Maywood Chemical Works, Division of Stepan Chemical Company. The current retail price for conventional-purity lithium metal in ton quantities is approximately $7.50 per pound. Magnesium-lithium alloys require high-purity lithium from which the sodium has been removed. This grade sells for $7.75 to $8.50 per pound.

Assuming an average price for lithium of $8.00 per pound, a price for aluminum of $0.23 per pound, and a price for magnesium of $0.35 per pound, the cost of the metallic materials going into LA141A would be as follows.

For every 100 pounds of alloy, 14 pounds of lithium would be required at a cost of $112; 1 pound of aluminum would be required at $0.23; and 85 pounds of magnesium would be required at $29.75. This is a total of $142, or $1.42 per pound of alloy.

This, of course, is the cost of the material in the sheet as it is shipped out the producer's door. It does not include the cost of the scrap generated to produce the sheet; of the flux that may have been used in melting; of the argon or helium atmosphere that is necessary to protect the alloy during melting; or of utilities, labor, and overhead.

Since the largest raw-materials cost is for lithium, it is interesting to see how reduced lithium prices might affect the cost of the alloy. If the price of lithium were reduced to $5 per pound and aluminum and magnesium prices were to remain the same, the net cost in the alloy material would be $1 per pound. If lithium could be reduced to $3 per pound (which may be in the realm of possibility), the net cost of the alloy materials would be $0.72 per pound.

By using $8-per-pound lithium and by applying the rule of thumb that the price of the mill product should be two to four times the cost of the raw material, the price of LA141A sheet might be expected eventually to be approximately $5 per pound.

What are the chances for a reduction in the cost of the raw materials? Presumably, the cost of aluminum and magnesium will not be reduced. However, the price of lithium has decreased from over $10 per pound 18 years ago to its present price, in spite of the decrease in value of the dollar. There is every reason to believe that the lithium price will continue to decrease if the demand increases. The cost of lithium metal is closely related to the cost of lithium chloride because the metal is made by the electrolytic reduction of lithium chloride to lithium and chlorine. It requires 6 pounds of the chloride to make 1 pound of lithium metal. The present retail price of lithium chloride is $0.80 per pound; thus the raw materials going into a pound of lithium metal cost $4.80.* The cost of lithium chloride is the largest single factor in the cost of lithium; electric power, manpower and other cost items are relatively small. The current cost of lithium chloride, as well as the cost of lithium metal, is closely related to the production volume. Since the lithium chemicals industry is now operating at roughly one-third of its capacity, any increase in production should reflect on the cost of the products.

Unfortunately, the production of lithium metal is not the largest factor in the lithium chemicals industry, and a modest increase in the use of magnesium-lithium alloys would not greatly affect the production of lithium carbonate, which is the starting material for the chloride. Thus, in 1960 metallurgical applications of lithium compounds and metal consumed 1 000 000 of the 9 300 000 pounds of lithium carbonate produced (ref. 41). For 1970 the estimated consumption of carbonate by industry is as shown in table 6.

It is believed that the price of lithium metal will continue to be reduced gradually because of increased demand for all lithium chemical products. Probably no major reduction in the price of lithium metal, e.g., to $5 per pound, will result solely from the production of magnesium-lithium alloys; nor will any reduction in lithium metal price bring about a major decrease in the price of the alloys.

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*Based on retail prices; the cost to the producer is assumed to be substantially lower.

TABLE 6.—*Estimated Consumption of Lithium Carbonate by Industry, 1970*

[Ref. 41]

Industry	Consumption in pounds of carbonate equivalent
Lubricating greases	2 500 000
Ceramics	4 500 000
Air conditioning	3 000 000
Metallurgy	2 700 000
Storage batteries	700 000
Synthetic rubber	300 000
Miscellaneous	800 000
Total	14 500 000

Scrap

Information on the amount of scrap generated during the production of magnesium-lithium alloys is not available from Brooks and Perkins. A normal scrap loss in the melting and rolling or extrusion of conventional metals, such as copper and aluminum, can be expected to be 20 to 30 percent. For materials more difficult to handle (for example, commercial magnesium alloys), the figure is probably closer to 40 percent. If losses of this magnitude are encountered in the conventional metals, it would not be surprising if the scrap loss in magnesium-lithium alloy production were as high as 60 percent, principally because optimum melting and scrap-recycling methods have not been developed. Brooks and Perkins recycles its scrap. However, it is understood that they are not using flux in the melting process. Since flux is usually necessary to separate the oxide and nonmetallic material from a metal, the recycling operation probably does not salvage all of the scrap generated.

Depending on the efficiency of the melting and refining practice, the scrap loss could be, and probably is, a major source of cost in magnesium-lithium alloy production.

Future Usage of Magnesium-Lithium Alloys

There is no doubt that future use of magnesium-lithium alloys will be oriented principally toward the space-hardware industry. Naturally, the growth of this usage will depend on the policies of the U.S.

Government. It is believed that, even without reductions in current prices, the magnesium-lithium alloy applications in space components will increase gradually if the present rate of effort in space exploration is maintained. The requirements to reduce weight as space-flight vehicles increase in size is a strong incentive to make use of the alloys.

Although there are few facts available on which to base a prediction, an annual consumption of 1 to 2 million pounds of mill products for space application would not be surprising 5 to 10 years from now. This usage will probably not become a reality until the Apollo program is successful and lunar exploration actually begins. At that time it will be necessary to construct large quantities of space equipment from the lightest metals available, and the magnesium-lithium alloys should be very much in demand.

It is not possible at this time to consider space applications as being commercial. However, in 10 to 20 years it is expected that private industry, as well as the Government, will have invested heavily in space communications and, possibly, in equipment for use in lunar travel and exploration. It is to this kind of industry that the magnesium-lithium alloys will become important.

Concerning applications that are commercial by today's standards (e.g., building construction, automobiles, household goods), it is impossible to predict in quantitative terms the extent to which magnesium-lithium alloys will be used. Since the outstanding feature of the alloys is their light weight, it is logical to assume that the commercial aircraft industry will be the first to use the alloys. Expected applications will be brackets, mounts, boxes for electronic equipment, and other nonstructural components comparable with aerospace parts described in this report. The alloys will be used in advanced aircraft in cases where weight penalties are most critical and cost of the material is of secondary importance.

The magnesium-lithium alloys are not expected to compete extensively with conventional magnesium or aluminum alloys in automobiles, building construction, appliances, and other commercial applications in the foreseeable future. Cost is the primary factor in such uses, and there is little possibility that the cost of magnesium-lithium alloys can ever be as low as that of magnesium or aluminum.

Regarding cost, it must be recognized that the light alloys provide more volume of material for a pound of weight. Thus, a pound of LA141A alloy is equivalent to 2 pounds of aluminum on a volume basis. However, this relationship is not usually considered by most manufacturing companies.

There is some reason to believe that magnesium-lithium alloys might compete more successfully with plastics than with other metals in commercial applications. The alloys have about the same weight as plastics but have much greater rigidity and strength. Again, cost is a major factor in the competition between plastics and metals. The magnesium-lithium alloys probably will be used only where properties are more important than cost.

Concepts for Increased Use of Magnesium-Lithium Alloys

This survey revealed that one or two companies are beginning to make effective use of the magnesium-lithium alloys. Even in these cases there are many other applications in which the alloys might be used to achieve weight reductions, and such applications are being studied as time and funds permit. The survey also showed that the present usage of the alloys by organizations engaged in space-vehicle development is very small compared with their potential usage since these alloys can save weight in components and systems in which weight savings are critically needed.

The effect of widespread use of the alloys in the space industry on their long-range use in other fields cannot be assessed at this time. However, in the case of titanium, increased use in defense and space applications brought about reductions in the cost of production. This has made it possible for commercially-oriented companies to start using titanium on a modest scale.

DISSEMINATION OF INFORMATION

There has always been a certain amount of apathy by the aircraft industry toward the use of magnesium. This was caused, in part, by poorly conceived early designs that called for magnesium when the material should not have been used or should have been used more conservatively. The apathy results also from ignorance of magnesium and from the natural tendency of designers and engineers to use materials that they have used before.

During this survey the impression was obtained that in the various aerospace organizations contacted, including NASA agencies, many key persons were either uninformed or misinformed about the magnesium-lithium alloys. For example, they were not aware of the applications in which the alloys have been successfully used to date.

RESEARCH AND DEVELOPMENT

Research and development are needed on the following problems.

Melting and Casting

As stated earlier, the present method of melting and casting is not optimum. The first melting practice used in this country was developed at Battelle. It consisted of melting under a LiCl–LiF flux. Later, alloys were melted at Battelle under argon or in a partial vacuum. Dow has used variations of the flux-melting process. Brooks and Perkins apparently is using the argon process.

It is felt that the optimum melting and casting process should make use of flux to clean the metal and permit recycling of scrap; it should also utilize an inert atmosphere or vacuum to avoid further oxidation of the melt.

The development of a process that might be applied to production will require a fairly long-range effort, possibly 2 years. This research is recommended as one avenue by which the cost of the alloys might be reduced.

Corrosion-Protection Treatments

Several treatments developed originally for commercial magnesium alloys have been applied with fair success to magnesium-lithium alloys. These are the Dow 17, HAE,* fluoride-anodize, and stannate treatments. All of them require subsequent paint coatings, preferably baking or room-temperature curing resins, for protection in outdoor, salt-air, or humid environments. No coating process has been found that will pass with complete success the most stringent military corrosion tests, e.g., MIL–E–5272.

Concerning plated coatings, a limited research effort has been made to develop electroplated or chemically plated coatings of tin, nickel, and other metals. As yet no metallic coating process is completely satisfactory for the magnesium-lithium alloys. These coatings are needed (1) for soldering electrical connections to magnesium-lithium hardware and (2) for protection in certain environments.

Research is needed to develop improved coatings of both metallic and nonmetallic types and to evaluate the existing military corrosion-test specifications in terms of their applicability to the environments in which magnesium-lithium alloys are expected to be used.

Brazing Alloy and Process Development

Although the magnesium-lithium alloys are readily weldable, there is no brazing filler metal that will work successfully with these alloys.

*Named for the inventor of the process, H. A. Evangelides.

Here again, research is needed to develop a brazing alloy and a suitable process for brazing magnesium-lithium alloys.

Evaluation of New Alloys

The LAZ933 (Mg–9%Li–3%Al–3%Zn) alloy, which was suggested by the recent Battelle research as a possible candidate for applications in which a higher strength material than LA141A is needed, should be evaluated more thoroughly. Additional data are needed on its thermal stability, mechanical properties, fabrication characteristics, and corrosion resistance before the alloy can be made on a production basis. The same type of effort should be applied to the Frankford Arsenal alloy, Mg–14%Li–3%Ag–5%Zn-2%Si.

Appendix: Current Specifications for LA141A Alloy

This appendix presents excerpts from specifications that have been released on LA141A alloy. Requirements for identification of the material, flatness, and other requirements not necessarily specific to this particular alloy have been omitted.

AEROSPACE MATERIAL SPECIFICATION
AMS4386 JUNE 30, 1964

Magnesium-alloy sheet and plate

14.0Li-1.25Al (LA141A-T7) stabilized.

Application

Primarily for components requiring weldability and good formability with low density for low-temperature and low-stress usage.

Composition

	MINIMUM	MAXIMUM
Lithium	13. 0	15. 0
Aluminum	1. 0	1. 50
Manganese	----	0. 15
Silicon	----	0. 10
Copper	----	0. 04
Nickel	----	0. 005
Iron	----	0. 005
Sodium	----	0. 005
Total of other impurities	----	0. 30
Magnesium	Remainder	------

Condition

Stabilized at 350° F ±24 (176.7° C ±14) for 3 to 6 hours and acid-pickled.

Tensile properties

Nominal thickness, inch	Minimum tensile strength Lb/in², min	Yield strength at 0.2% offset or at extension indicated (E=6 000 000)		Elongation, % in 2 in. or 4 D, min
		Lb/in², min	Extension under load, in. in 2 in.	
0.010 to 0.090, incl.	19 000	15 000	0. 0090	10
0.091 to 0.250, incl.	19 000	14 000	0. 0087	10
0.251 to 2.000, incl.	18 000	13 000	0. 0083	10

Protective treatment

Unless otherwise specified, material shall be oiled with a light corrosion-inhibiting oil. Material shall be protected during shipment and storage by interleaving with suitable page sheets.

BROOKS AND PERKINS, INC.
SPECIFICATION BP-S-125 REVISION B
MAGNESIUM-LITHIUM ALLOY LA141A
SHEET AND PLATE

Chemical composition

Lithium	13.00–15.00
Aluminum	1.00– 1.50
Manganese	0.15 max
Silicon	0.10 max
Copper	0.04 max
Iron	0.005 max
Nickel	0.005 max
Sodium	0.005 max
Total of other impurities	0.30 max
Magnesium	Remainder

Temper

Magnesium-lithium sheet and plate shall be supplied in the stabilized condition, 300° F, 3 to 6 hours.

*Mechanical properties**

Thickness	Tensile strength, lb/in², min	Yield strength at 0.2% offset, lb/in², min	Elongation in 2 inch. % min
0.010–0.090	19 000	15 000	10
0.091–0.250	19 000	14 000	10
0.251–2.00	18 000	13 000	10

*Properties of plate greater than 2 inches and of extrusions shall be mutually agreed upon by purchaser and seller.

Tolerances

Tolerances of magnesium-lithium sheet and plate shall comply with Federal Standard No. 245 for all thicknesses. Flatness tolerances shall comply with paragraphs 3a, 3b, and 3c.

Finish

The material shall be supplied with a standard mill finish—"Acid-Pickled and Oiled"; under 0.020 in. oiled.

Protective treatment

The material shall be treated with a light corrosion-inhibiting oil, American Anti-Rust Oil No. 12 or equivalent, before shipment.

IBM, FEDERAL SYSTEMS DIVISION
SPECIFICATION 6009417

Magnesium Alloy Sheet and Plate
14Li-1.25Al (LA141X)

The IBM specification is identical to AMS–4386 with respect to alloy composition and tensile properties. It also specifices the 3- to 6-hour, 350° F stabilization treatment.

LOCKHEED MISSILES AND SPACE COMPANY
LAC 07–4194A DECEMBER 26, 1963

Lockheed Missiles and Space Company has prepared a tentative specification. Since the specification has not been officially released, it will not be quoted here. It does not differ materially from the information presented above.

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